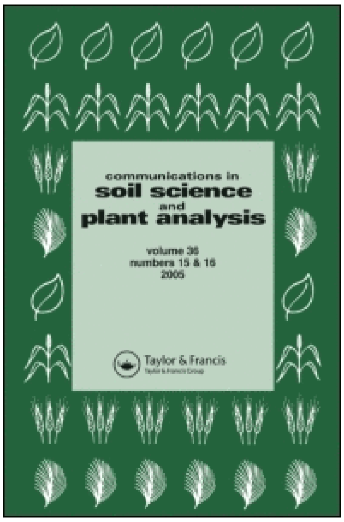

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Tillage intensity and crop residue effects on nitrogen and carbon cycling in a Vertisol

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Tillage Intensity and Crop Residue Effects on Nitrogen and Carbon Cycling in a Vertisol

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ABSTRACT

The objective of this study was to examine the impact of tillage intensity and crop residue on carbon (C) and nitrogen (N) cycling in a Vertisol. Soil samples (0-10- and 10-20-cm depth) were collected from a Houston Black soil (fine, montmorillonitic, thermic Udic Pellusterts) with three different levels of tillage intensity, varying from no tillage to complete residue burial. The experiment was a split plot design with five replications. The main plots were three crop species [corn (*Zea mays* L.), grain sorghum (*Sorghum bicolor* [L.] Moench), and soybean (*Glycine max* [L.] Merr.)] and the subplots were three levels of tillage intensity (chisel tillage, reduced tillage, and no tillage). Total N, organic C, inorganic N, and C:N ratio were measured on soil samples as well as the potential C mineralization, N mineralization, C turnover, and C:N mineralization ratio during a 7- and 30-d incubation. Chisel tillage reduced total N, C mineralization, and C turnover at the 0-10-cm depth compared to the other conservation tillage systems. Following corn production, soil organic C increased and C mineralization and C turnover were decreased at the 10-20-cm depth compared to the other crop species. This data indicates that, in

the short term, tillage systems may control soil organic C at the soil surface, while changes in plant rooting may control soil organic C storage at deeper soil depths in Texas Vertisols.

INTRODUCTION

The sustainability of any crop production system depends on maintaining adequate soil plant nutrients and organic C levels. Residue management, which is normally altered by tillage systems, is a fundamental constituent for the maintenance of soil and soil nutrients. Tillage systems which limit the incorporation of plant residues have generally been shown to conserve nutrients by reducing soil erosion losses (Torbert et al., 1996; Chichester and Richardson, 1992), but other effects on soil nutrient conditions are less clear. For example, conservation tillage systems have been reported to increase soil N retention as a result of immobilization (Gilliam and Hoyt, 1987), and to increase N losses from both leaching (Tyler and Thomas, 1977) and denitrification (Gilliam and Hoyt, 1987). Soil moisture and temperature, which are affected by tillage systems, change C and N dynamics (Wood et al., 1991; Tracy et al., 1990). When comparing soil nutrient storage in cultivated soils compared to adjacent forested soils, Ellert and Gregorich (1996) concluded that while there were inherent differences in soil properties for C and N storage for different sites, the overriding effect on the observed change in soil C and N was due to management. Conservation tillage leads to increases in soil organic carbon (SOC) concentration near the surface (Wood et al., 1990; Wood et al., 1991; Potter and Chichester, 1993; Franzluebbers et al., 1995), but the ability of the soil to sequester C may be climate dependent (Potter et al., 1998).

In addition to residue management through tillage, crop sequence may also affect temporal soil C and N concentrations. In the humid Southeast, crop rotations that include corn have been shown to promote SOC (Wood et al., 1991). Havlin et al. (1990) reported that in long term studies in Kansas, continuous soybeans reduced SOC and total N under no-till compared to a soybean-grain sorghum or a continuous grain sorghum rotation. In the dryer climates of Texas and Colorado, SOC was negatively impacted by less intensive cropping systems involving fallow periods (Potter et al., 1997; Franzluebbers et al., 1995; Wood et al., 1990; Wood et al., 1991).

Vertisols are soils with a high shrink/swell potential and are difficult to manage because of their physical characteristics. These soils have a limited range of soil water content when soil tillage can be performed (Potter and Chichester, 1993). These characteristics lead to difficulties when implementing conservation tillage practices for erosion control and environmental protection. As with other soil types, the soil nutrient status is extremely important for maintaining crop production systems. The objective of this study was to determine the impact of tillage intensity within different crop species on the C and N dynamics in a Vertisol.

TABLE 1. Summary of annual tillage treatment operations.

Operation	Chisel†	Reduced	No-tillage
Flail chop residue	X	X	
Chisel plow	X		
Tandem disk	X	X	
Field cultivate	X		
Rebed	X	X	
Slot plant	X	X	X

†Chisel = conventional chisel tillage system, reduced = reduced tillage system.

MATERIALS AND METHODS

A tillage study was initiated in 1991 at the Grassland, Soil and Water Research Laboratory, at Temple, TX (31°05'N, 97°20'W) on a Houston Black clay soil (fine, montmorillonitic, thermic Udic Pellusterts) with three levels of tillage intensity. The tillage intensities were imposed on an existing tillage study consisting of no tillage and conventional tillage systems that had been maintained for 10 years. The experimental design was a split-plot with a randomized complete block with five replications. The main plots were three crop species and the subplots were three tillage levels. Statistical analyses were performed using GLM procedure of SAS (SAS Institute, 1985), and means were separated using least significant difference (LSD) at an *a priori* 0.10 probability level. The three tillage systems imposed in this study were: 1) chisel tillage (Chisel), 2) reduced tillage (reduced), and 3) no tillage (no-till). Field operations for the three tillage systems are given on Table 1.

The chisel tillage system consisted of flail-shredding residue, tandem disking, chisel tilling, tandem disking, field cultivating, and rebedding. The reduced tillage system consisted of flail-shredding residue, tandem disking, and rebedding. The no-till system consisted of no pre-plant tillage and planting with a slot planter. The chisel tillage system was considered to be a conventional tillage system, while the other two tillage systems are forms of conservation tillage.

The management system in these plots (61.0 m long) included raised wide beds 1.5 m wide, 0.15 m high, separated by 0.5 m furrows acting as traffic lanes and surface drainways (Morrison et al., 1990). Three crop rotations, consisting of corn (*Zea mays* L.) followed by grain sorghum [*Sorghum bicolor* (L.) Moench] followed by soybean [*Glycine max* (L.) Merr.], were applied each year. The crops received an annual application of 17 kg P ha^{-1} to soybean, 168 kg N ha^{-1}, and 37 kg P ha^{-1} to corn, and 140 kg N ha^{-1} and 32 kg P ha^{-1} to grain sorghum.

Soil samples were collected from the study site to investigate the cumulative effect of tillage intensity and fertility level on soil nutrient status and soil microbial activity. These samples were collected on January 4, 1994 at 0-10- and 10-20-cm depths from plots subsequent to the harvest of each of the crop species. Soil samples were stored at 5°C until processing for laboratory and incubation analyses. Subsamples of the soils were dried (60°C), ground to pass a 0.15-mm sieve, and analyzed for total N on a FISON NA1500 nitrogen and carbon determinator (Fison Instruments, Inc., Dearborn, MI). Soil organic C was determined with a LECO CR12 Carbon Determinator (LECO Corp., Augusta, GA; Chichester and Chaison, 1992).

Methods used by Wood et al. (1990) were utilized for determinations of potential C and N mineralization of soil samples. Soil inorganic N (NO_2-N + NO_3-N and NH_4-N) was extracted with 2M KCl and measured (before and after incubation) by standard colorimetric procedures using a Technicon Autoanalyzer (Technicon Industrial Systems, 1973a, 1973b). Sieved soil samples (2 mm sieve) were weighed (25 g; dry weight basis) and placed in plastic containers. Deionized water was added to adjust soil water content equivalent to -20 kPa at a bulk density of 1.3 Mg m^{-3}. The containers were placed in sealed glass jars with 20 mL of water, for humidity control, and a 20 mL vial of 1M NaOH, as a CO_2 trap. The jars were incubated in the dark at 25°C and removed after 7 days and 30 days. Carbon dioxide in the NaOH traps was determined by titrating the excess base with 1M HCl in the presence of $BaCl_2$. Potential C mineralization was the difference between CO_2-C captured in sample traps and in blanks. Potential N mineralization was the difference between final and initial inorganic N contents for the incubation. The C mineralization divided by total SOC was used to calculate C turnover.

RESULTS

Residue Inputs

The 1993 grain yields for the three crops as affected by the three tillage treatments are present in Table 2. These yields represent those observed for the tillage systems for the three crops from the immediately preceding year. A more detailed description of the corn and grain sorghum growth and productivity within these tillage systems was reported previously by Potter et al. (1996). Differences were observed in production between both the crop species and the tillage system used. With corn, no-till tended to reduced yields, whereas no difference was observed among tillage systems with grain sorghum (Potter et al., 1996). A much lower production was observed with soybean, with a tendency for the yields to be reduced with the no-till treatment (Table 2).

Soil Chemical Analysis

At the 0-10-cm depth, total N was reduced in the chisel tillage treatment compared to the other tillage treatments (Table 3). However, at the 10-20-cm

TABLE 2. Effect of tillage system on grain yield in 1993.†

Crop species	Chisel‡	Reduced	No-till	Average
	(kg ha^{-1})			
Corn	9154	9230	7923	8869
Grain sorghum	6212	6234	6491	6312
Soybean	1310	1252	673	1078

†Values represent means of 5 replicates.

‡Chisel = conventional chisel tillage system, reduced = reduced tillage system, no-till = no tillage.

depth, total N content tended to be increased in the chisel tillage treatment compared to the other tillage treatments. This was perhaps attributable to the physical mixing of the soil with chisel plowing, where plant residues and N fertilizers were mixed to a deeper depth.

Stratification of total N content in the soil profile with conservation tillage systems, in general, would be consistent with work on Vertisols and other soil orders indicating that most of the impact of tillage systems is observed in the top

TABLE 3. Effect of tillage system on soil inorganic N, total N, organic C content, and C:N ratio at 0-10- and 10-20-cm depth increments.†

Tillage‡	Inorganic N	Total N	Soil organic C	C:N
	(mg kg^{-1})	(g kg^{-1})		(g g^{-1})
<u>0-10 cm</u>				
Chisel	16.3 a	2.45 a	20.1 a	8.2 a
Reduced	24.3 b	2.64 b	21.8 a	8.0 a
No-till	16.1 a	2.72 b	20.7 a	7.8 a
<u>10-20 cm</u>				
Chisel	22.5 a	2.12 a	17.9 a	8.0 a
Reduced	19.6 a	2.05 a	17.2 a	8.4 a
No-till	29.5 a	2.03 a	17.1 a	8.4 a

†Values represent means of 5 replicates. Means within a column followed by the same letter do not differ significantly (0.1 level) as determined by LSD.

‡Chisel = conventional chisel tillage system, reduced = reduced tillage system, no-till = no tillage.

TABLE 4. Effect of crop species of on soil inorganic N, total N, organic C content, and C:N ratio at 0-10- and 10-20-cm depth increments.†

Crop species	Inorganic N	Total N	Organic C	C:N
	(mg kg^{-1})	—— (g kg^{-1}) ——		(g g^{-1})
0-10 cm				
Corn	25.8 a	2.63 a	20.06 a	8.3 a
Grain sorghum	15.0 b	2.59 a	20.69 a	7.6 a
Soybean	16.0 ab	2.59 a	21.84 a	8.1 a
10-20 cm				
Corn	29.7 a	2.13 a	19.34 a	8.4 a
Grain sorghum	18.5 a	1.97 a	15.72 b	7.9 a
Soybean	23.4 a	2.02 a	17.09 ab	8.4 a

†Values represent means of 5 replicates. Means within a column followed by the same letter do not differ significantly (0.1 level).

5 cm of soil (Tracy et al., 1990; Balesdent et al., 1990; Dalal, 1989; Potter and Chichester, 1993; Morrison and Chichester, 1994). Furthermore, increased losses of soil nutrients due to erosion with the conventional chisel tillage system compared to the two conservation tillage systems may have contributed to lower total N content in the 0-10-cm depth (Torbert et al., 1996).

Crop species had no significant effect on total N or SOC concentration at the 0-10-cm soil depth (Table 4). At the 10-20-cm depth, there was a tendency for the corn to have a higher total N and SOC concentration compared to the other crop species. A significant difference was noted for SOC between corn and grain sorghum at this depth (Table 4). Inorganic N content tended to be higher in corn compared to the other crop species at both soil depths, with corn having a significantly higher inorganic N content at the 0-10-cm depth compared to grain sorghum. No significant difference for C:N ratio was observed between crop species at either soil depth (Table 4).

Soil Incubation

Incubation of soil, from samples at the 0-10- and 10-20-cm depths, indicated that most of the C mineralization occurred within the first 7 days of incubation (Table 5). Soil incubation for the 0-10-cm sample indicated that increasing tillage intensity tended to increase C mineralization and C turnover (C mineralization/SOC), with the reduced tillage and no-till tillage systems having significantly lower C mineralization and C turnover during both the 7- and 30-d incubation

TABLE 5. Effect of tillage system on C mineralization, C turnover, N mineralization, and C:N mineralization ratio at 0-10-and 10-20-cm depth increments.†

Tillage‡	C Mineralization 7 days	C Mineralization 30 days	C Turnover 30 days	N Mineralization 30 days
	(mg kg^{-1})			
<u>0-10 cm</u>				
Chisel	196 a	281 a	1.59 a	2.07 a
Reduced	123 b	152 b	0.71 b	4.41 a
No-till	128 b	163 b	0.88 b	7.23 b
<u>10-20 cm</u>				
Chisel	92 a	155 a	0.94 a	-3.31 a
Reduced	88 a	115 a	0.72 a	-2.04 a
No-till	96 a	128 a	0.83 a	-3.02 a

†Soil incubated at 25°C for 30 days. Values represent means of 5 replicates. Means within a column followed by the same letter do not differ significantly (0.1 level).

‡Chisel = conventional chisel tillage system, reduced = reduced tillage system, no-till = no tillage.

periods compared to the chisel tillage system (Table 4). However, increased tillage intensity tended to decrease N mineralization, with the no-till system having a significant increase in N mineralization compared to the chisel tillage system (Table 5).

At the 10-20-cm depth, no significant difference was observed between tillage systems for C mineralization, C turnover, or N mineralization at 7 or 30 d. The N mineralization at this depth was negative indicating that net N immobilization has occurred.

Significant differences were observed between crop species for the incubation portion of the study. As was observed with the tillage systems, most of the measured C mineralization occurred within the first 7 days (Table 6). Carbon mineralization in soils under corn tended to be reduced compared to the soils cultivated with other crop species at both soil depths, with C mineralization under corn being significantly lower compared to that under soybeans after 7 d at the 0-10-cm depth and after 30 d at the 10-20-cm soil depth. Likewise, a trend for soil under corn to have a lower C turnover compared to soils under the other crop species was observed. A significant reduction was observed between the effect of corn and grain sorghum at the 10-20-cm depth. However, no significant

TABLE 6. Effect of crop species on C mineralization, C turnover, N mineralization, and C:N mineralization ratio at 0-10- and 10-20-cm depth increments.†

Crop species	C Mineralization 7 day	C Mineralization 30 day	C Turnover 30 days	N Mineralization 30 days
	(mg kg^{-1})			
0-10 cm				
Corn	93 a	132 a	0.62 a	5.48 a
Grain sorghum	153 ab	235 a	1.43 a	1.47 b
Soybeans	196 b	229 a	1.12 a	6.76 a
10-20 cm				
Corn	74 a	106 a	0.58 a	-1.25 a
Grain sorghum	112 a	143 ab	1.01 b	-3.16 ab
Soybeans	89 a	148 b	0.89 ab	-3.96 b

†Soil incubated at 25°C for 30 days. Values represent means of 5 replicates. Means within a column followed by the same letter do not differ significantly (0.1 level).

differences were observed for C mineralization or C turnover at 30 d for the 0-10-cm depth (Table 5).

Significant differences were also observed for N mineralization, but these differences did not correspond to differences observed for C mineralization. At the 0-10-cm soil depth, N mineralization was significantly lower with grain sorghum compared to the other crop species, and no indication was noted for the corn having reduced N mineralization compared to soybean.

At the 10-20-cm depth, as was observed with the tillage systems, N mineralization was negative indicating a net N immobilization. At this depth, the lowest level of N immobilization (least negative value) was with corn indicating that N limitations were less with the corn (Table 6). The highest immobilization was observed with soybean, which indicated that reductions in observed C mineralization and C turnover were not due to N limitations.

DISCUSSION

From the soil incubation, significant reductions in C mineralization at both 7- and 30-d incubations were observed among tillage treatments. The C turnover was also reduced with the conservation tillage system as compared to the chisel tillage system. Since there was no significant interaction with crop species, the effects of tillage would have an overriding effect on shifts in soil C storage. This was consistent with findings of Potter et al. (1998) from soil sampled across a 1,100-km transect within Texas, which indicated that no-till systems could increase soil C storage.

The no-till system increased N mineralization at the 0-10-cm depth, though these changes did not correspond to differences in C mineralization. The greatest N mineralization occurred with the no-till system, indicating that the observed trends for a reduction in C mineralization and C turnover with the two conservation tillage systems were not due to N limitations. Therefore, N immobilization alone was not the factor limiting C mineralization observed in the conservation tillage systems. This was consistent with a previous study conducted to examine the effect of tillage intensity on these soils, which demonstrated that the accumulation of C in conservation tillage systems could have been of more recalcitrant forms of C compared to intensively tilled systems (Torbert et al., 1997).

At the 0-10-cm depth, no difference was observed for C mineralization or C turnover at the 30-d incubation, corresponding to no difference in SOC. The most plausible explanation for these data is that the soil was already near an equilibrium level of SOC before the samples were taken. At this depth, most of the easily decomposable biomass had already been utilized by soil microorganisms.

At the 10-20-cm depth, a significant difference was observed in both the C mineralization and C turnover with corn compared to the other crops, which corresponded to an increase in the SOC level at this depth. These data indicated that decomposition of SOC at this depth was not as far along, as evidenced by the N immobilization. This would also indicate that the SOC was not as close to an equilibrium as compared to the surface soil. The reduction in C mineralization with corn residue, however, was apparently not due to N limitations with the corn, because the level of N immobilization was significantly lower in corn compared to the soybean (as indicated by a less negative number) (Table 6). These data indicate that differences in crop roots may be the most important factor in determining the impact of different crops on C storage.

The impact of residue input into the soil system appeared to have very little impact on soil total N and SOC levels. While differences in crop yields were observed from the preceding crop (Table 2), differences were only observed for SOC at the 10-20-cm depth for corn compared to grain sorghum, with no difference between corn and soybean (with smaller biomass inputs). These results were consistent with those reported by Potter et al. (1997) in a Pullman clay loam soil which indicated that, whereas the biomass input into continuous grain sorghum was much greater compared to continuous wheat, SOC storage in soils under continuous wheat was slightly higher than under continuous grain sorghum.

While both residue type and input levels into the plots were very different, by January of the following year, there was little treatment effect on SOC observed at the 0-10-cm soil depth (Tables 4 and 6). There were also no significant interactions between the tillage systems and crop species, although the quantity and quality of the biomass inputs were clearly different. These data indicate that in the short term changes in plant species rooting may impact SOC storage at deeper depths in Vertisols in Texas.

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